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Amazonian deforestation: Regional and global issues*

by

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Abstract

How does the deforestation of Amazonia affect global and regional climates? What are the roles of these changes on Amazonian ecosystems? We have concluded that the relation between Regional Climate Changes (RCC) and Global Climate Change (GCC) is directly associated with anthropogenic activities and therefore sensitive to social, economical and political interventions. The RCCs are caused by actions within the realm of the Brazilian sociopolitical scenario, and prone to changes through the implementation of public policies regulating the sustained use of the renewable resources. The GCCs belong to an international arena, and are caused by the high emission rates of greenhouse gases by the developed countries. The effects of the RCCs could be abated if the developed countries would endeavor to reduce the present emission levels as documented in IPCC meetings and collaborate in the implementation of a regulation to curb the carbon emissions, in accordance to the Kyoto Protocol.

Keywords: **Climate change, global change, carbon, deforestation, emission, Amazon, Neotropics.**

Resumo

Como o desmatamento da Amazônia causa Mudanças Climáticas Regionais (MCR) e contribue para as Mudanças Climáticas Globais (MCG)? Qual é a influência destas mudanças sobre os ecossistemas amazônicos? Constatamos que a relação entre MCR e MCG esta diretamente ligada à ação antrópica e os cenários das alterações descritas apontam impactos sobre os sistemas naturais, sociais e econômicos. As MCR são ocasionadas por vetores e atores internos ao cenário político e social brasileiro, podendo ser alteradas através da implementação de políticas públicas ligadas ao uso sustentável dos recursos naturais

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renováveis. Por sua vez, as MCG são causadas por um cenário internacional, originadas pelas altas taxas de emissão de GEE dos países desenvolvidos. Os efeitos das MCG poderiam ser diminuídos caso os países desenvolvidos assumissem a redução dos níveis de emissão, nos números acordados pela Convenção Quadro sobre Mudanças Climáticas e cooperassem na implementação das regras para projetos de sequestro de carbono, conforme o Protocolo de Kioto.

Introduction

Global climatic changes and biodiversity

The global climate changes that have occurred throughout the evolution of the planet were important factors in altering the abiotic variables and conducive to new organizations within the ecosystems (SIGMAN & BOYLE 2000). These changes were brought about either by external factors such as changes in the Earth's rotation axis with respect to the sun, orbital variations and collision with comets or by internal factors such as volcanism or depletion of atmospheric carbon due to biological activities. In addition to these natural factors, there are those originated by mankind's demands and industrial growth (VITOUSECK et al. 1997).

Mankind has been intensely changing the global environment, introducing new species in places where they had never occurred and thus contributing to the extinction of some of the species. We have disturbed the natural biogeochemical cycles by changing the chemical compositions of the soil and atmosphere. We are also being responsible for the increasing loss of natural habitats and the fragmentation of ecosystems. Natural ecosystems have been replaced by agricultural and urban systems (HAMMOND 1993).

The CO_2 emission rate has increased by 30 % during the last three centuries. The larges increase has occurred in the last 40 years associated with the increased consumption of natural fuels and the burning of biomass, mainly in the tropical rain forests. It is believed that no less than about of 8 Gt of carbon in the form of CO_2 are released into the atmosphere each year due to anthropogenic activities. About 4.7 Gt are absorbed by the terrestrial biota and oceans leaving 3.3 Gt accumulated in the atmosphere (IPCC 1995).

Anthropogenic activities are clearly associated with a loss of biodiversity. Although extinction of species is commonplace in geological terms, the present increase in the extinction rates is certainly an event caused by mankind. Considering only birds, mammals, fishes and plants, we have promoted the extinction of some 5-20 % of the total number of the existing species. The present extinction rates are between 100-1000 higher than those existing before the appearance of the human being on the earth's surface (STUART CHAPIN III et al. 2000).

Models combining the loss of habitats rate, the area versus species curve and the survival curve show, assuming a conservative scenario (PIMM & RAVEN 2000), that by the middle of the twenty first century 50,000 species within in each group of one million species will be extinct. If the worst scenario (present destruction rates of tropical forests) is assumed, together with a present biodiversity in all the tropical forests of the Earth of 10 million species, then the present extinction rate is 3 species per hour or 27,000 annually (MYERS et al. 2000).

Results

Amazonia and climate changes

How does the deforestation of Amazonia affect global and regional climates? What are the roles of these changes on the Amazonian ecosystems? These are the key questions of this study. Figure 1 is based on the premise that the present dynamic state of equilibrium of the atmosphere over Amazonia is sensitive to forcings that lead to climatic variations. These changes may be investigated from three different approaches:

Regional Climate Changes (RCC)

(1) These are internal anthropogenic changes stemming the way that people have been exploiting the natural resources of the region. The RCCs may result from changes in the surface vegetation which modify the solar energy and water budgets, or changes in the atmospheric composition, mainly due to the increasing concentrations of atmospheric CO_2 **(2)** as a byproduct of burning of forests **(3)**. The RCCs may be minimized or even reserved if adequate public policies for regional sustainable development will be implemented. The other two approaches deal with external factors to the region and are linked to the **(3)** Global Climate Changes (GCC).

RCCs may also be attributed to global climate changes ensuing from natural causes.

These changes are related to those in the solar intensity, variations of the planet's rotation axis inclination and to the eccentricity of its orbit, changes in volcanic activity and changes in the chemical composition of the atmosphere for example. There are well documented records on climatic oscillations in Amazonia that occurred during glaciations and as a result of short-term changes such as those associated with the El Niño. There is not much the society can do about these changes except to be ready to reduce their consequences.

Climate variations ensuing from man caused global climate changes.

Within this context, the deforestation of Amazonia has not been yet well determined from the quantitative point of view. Deforestation and the changes in land use imply in a transfer of CO_2 from the biosphere into the atmosphere, thus contributing to the amplification of the global climate effect which, in return, affects Amazonia. The predictions suggest that the larger effects of the global warming and its consequences will be primarily felt in the high latitudes, although they will not be negligible in the tropics (IPCC 2000).

Hydrological cycle in Amazonia and climate changes

The understanding of the hydrological cycle and its changes are fundamental in the studies of how climate changes affect the dynamics of the ecosystems in Amazonia.

The Amazon region is intercepted by the equator and lies between roughly 10°S and 5°N. It is exposed to the warm and humid trade winds, which blow from the eastern quadrant. The majority of the territory has a climate predominantly warm and humid

classified as Am, Aw and Af according to KOEPPEN's criteria. However, because the drainage basin of the Amazon River stretches to the Andes, northward to the Guyanas plateau and southward to the Central Brazilian Plateau, it has other climatologically distinct regions (SALATI & MARQUES 1984).

Solar energy

In Amazonia, the solar energy reaching the surface or the canopy of forests is more dependent on cloudiness rather than sun inclination.

On average, the solar energy reaching the upper portions of the canopy is about 50 % of that reaching the upper troposphere. Measurements at Manaus indicate that the maximum incident energy relation is in the order of 56 % from August to October, with a minimum of 30 % in December and January.

Incident energy averages about 400 cal/cm^2/day and about 73 % of the net energy is utilized in evaporating water, either directly or through the evapotranspiration. The remaining is used for heating the air and a small fraction (1-2 %), for the production of organic matter via photosynthesis (SALATI & MARQUES 1984).

Temperature

There is not much variation in the mean temperatures throughout the year, and means calculated for several localities (Table 1) differ little. Radiosonde measurements indicate the precipitable water for Manaus as 44 mm and 42 mm for Belém. The average for Amazonia was estimated as 35 mm. In total there is 0.38 x 10^{12} m^3 of liquid water in vapor over the Amazon. This is equivalent to the annual discharge of the Mississippi River to the Gulf of Mexico.

The mean temperature of the Amazonia is determined by:

- Its geographical location near the equator, associated to the air masses advected mainly from the Atlantic Ocean;
- The weakened cold fronts that manage to reach the region;
- The amount of water vapor in the atmosphere;
- Type of vegetative cover, and vegetation;
- Heat release due to the condensation of water vapor in the process of forming clouds.

From the information above, one can conclude that changes in the water vapor is content in the atmosphere will certainly imply changes of the solar radiation, like in the energy budget influencing the temperature.

Water vapor fluxes in Amazonia

Several studies were conducted using radiosonde data for Amazonia and its surroundings (MARQUES et al. 1980a, b), concluded that:

- Most of the primary water vapor penetrating the region comes from the Atlantic Ocean, as supported by the calculated fluxes for March, June, September and December. During the period from 1972 to 1975, when these measurements were made the deforestation rates were still small relative to the forested areas of the region. The flux was estimated at 9 to 11 x 10^{12} m^3 of water per year. Figures 2-5 show the water vapor fluxes over the region and their spatial variability. The fluxes change from southeast to northeast, following the incursion of the Intertropical Convergence Zone (ITCZ).

- Southward water vapor flux persists for the entire year for the latitudes below those of Carolina and Vilhena; despite the northward displacement of cold fronts, the flux is directed from Amazonia into Central Brazil and Pantanal.
- The water vapor that enters the region, specifically in wide stripe along the equator is insufficient to explain the observed precipitation.
- The southward water vapor that leaves the region, is about 40 % of the water vapor advected into the region.

The precipitable water increases from east to west, with the highest values found in Iquitos, Peru, while the water vapor fluxes decrease in the same direction, with maximum in Belém, Brazil.

Precipitation

The precipitation over the Amazonia averages 2,460 mm/yr, corresponding to a total volume of water of 15.04 x 10^{12} m^3/yr, if the area of the Amazonic Basin is considered to be 6,112,000 km^2. From this total, 6.6 x 10^{12} m^3/yr returns to the ocean based on an average discharge of 209,000 m^3/s at the mouth of the Amazon River (SALATI 1985).

The precipitation has a spatial variability, with values of 1600 mm/yr along a stripe oriented north-south, that includes part of the oriental Amazonia. In general, the precipitation is higher near the coastal areas (> 3,000 mm/yr) decreasing westward (1,600 mm/yr) to increase again to values above 3,000 mm/yr in the region of the upper Rio Negro, where it reaches extreme values of 9,000 mm/yr at the Andean slopes.

The precipitation also has a high temporal variability. One of the main characteristics is the 6 month lag between the maxima of precipitation. In Amazonia lying in the northern hemisphere, the rainiest period is in June/July, while for the part south of the equator, maximum precipitation occurs in February/March.

The temporal variability of the rain is closely related to the seasonal migration of the ITCZ near the coastal areas. The ITCZ oscillates in a south-north direction, following the maximum temperature changes of the ocean surface, which are 3 months out of phase with respect to the maximum solar heating due to the sun declination. A large area of low level water vapor flux convergence is also observed over continental Amazonia, but without any lag. In other words, this flux convergence follows the maximum solar heating, reaching its southernmost position in January during maximum heating in the austral parts of the region.

Water Budget

Since the pioneering measurements of the discharge of the Amazon River by OLTMAN, in 1967, there have been many other measurments using gradually more refined techniques. The estimated average discharge of the Amazon River at its mouth is 209,000 m^3/s, (annual discharge of 6.6 x 10^{12} m^3/yr).

To close the water budget, it is necessary to have an estimate of the evapotranspiration in the region and the well accepted value is 1,460 mm/yr (VILLA NOVA et al. 1976).

Therefore, for the whole Amazon Basin the water balance may be given in terms of the precipitation P (15.0 x 10^{12} m^3/yr), evapotranspiration (8.43 x 10^{12} m^3/yr) and river discharge (6.6 x 10^{12} m^3/yr). The water budget for the Amazonia as a whole is shown in Figure 6. This balance indicates that the advective water vapor flux is of order of 9 to 11 x 10^{12} m^3/yr while the Amazon River discharge (divergence of the water vapor

flux) is 6.6 x 10^{12} m^3/yr.

The amount of the water vapor that leaves the region is estimated at 3 to 4 x 10^{12} m^3/yr. Since the total precipitation corresponds to 15.05 x 10^{12} m^3/yr and the evapotranspiration is estimated at 8.43 x 10^{12} m^3/yr, the balance can be only fulfilled if there is an intense recirculation of water vapor within the region (SALATI & NOBRE 1991).

One method for evaluating the extent of recirculation of the water vapor is to examine the fractionation of oxygen and hydrogen isotopes contained in the water molecules, during the evaporation and condensation processes that take place during the hydrological cycle (SALATI & VOSE 1984).

Intensive field experiments were conducted between 1990 and 1994 with the purpose of characterizing the soil - plant - atmosphere interactions from the microclimatic point of view in areas with forests and pasture. These experiments were aspects of the Anglo-Brazilian Amazonian Climate Observation Study (ABRACOS) that involved a number of Brazilian and British researchers. It was possible to conclude that in response to a rampant deforestation with the Amazonian landscape replaced by pastures, there would be a reduction of 6 % to 20 % in the regional precipitation, depending on local topographical features. Comparative studies on the measurements of air temperatures between areas of pasture and native forests reveal a difference of 2.4 °C with higher values in the deforested areas (GASH et al. 1996).

The water cycle in Amazonia and the RCC's may be summarized as follows:

a) The primary water vapor originating in the Atlantic Ocean enters the region via trade winds and is precipitated. A large fraction of the rain water returns to the atmosphere in the form of vapor due to the evapotranspiration mechanism. This water vapor mixes with the residual primary vapor and produces new rain farther inland (Fig. 7).

b) The precipitation is formed by a mixture of the residual primary water vapor that originated over the ocean and the water vapor due to evapotranspiration.

c) The forest is not a simple consequence of the climatic conditions and its existence should be associated with the composition and structure of the soil. The atmospheric dynamics do strongly interact with the vegetative coverage of the surface and from this interdependency, it is possible to define the regional climate.

d) In addition to microclimatic changes, deforestation may also lead to changes in the regional climate. Predictions include a temperature increase and a decrease in precipitation.

e) The global warming, due to the doubling of the atmospheric CO_2 concentrations, is of the same order of magnitude as that stemming from a regional deforestation,.. Amazonia is under the effects of two powerful forcing mechanisms that can change its climate: the local/regional deforestation and the global atmospheric warming.

Future scenarios concerning global climate changes and their plausible effects on Amazonia

If the present trend of anthropogenic emissions of greeenhouse gases continues, there is a high possibility that global climate changes of appreciable magnitude will occur continuously during the next 100 years. Among them, the most dramatic for Amazonia will be the increase in temperature, changes in the precipitation patterns and modifications in the distribution of extreme climatic events such as droughts, floods, cold front

penetrations in the western part of the region, e.g., severe thunderstorms, gales and hailstorms. The predicted increase of the main sea level may bring about consequences to human settlement and the ecosystems existing along the coastal areas and the nearby banks of the water courses under tidal influences.

Presently, Global Climate Models (GCMs) have been used to estimate the impact of eventual global climate changes under the premises of changes in the greenhouse gas concentrations, valid until 2100. Scenarios of future global climate changes are predicted consistently with the input data fed into the numerical models. Various meteorological centers with appropriate computational facilities run their GCMs on an operational basis. Quite recently, the IPCC made public a study on future scenarios of emissions. Based on them as well as on results of 10 numerical simulations spanning from 1870 to 2100 (IPCC 2000) elaborated scenarios provoked by climate changes for different parts of the planet. Among them, the northern part of the South American continent, including, of course, Amazonia.

The IPCC studies on future emissions introduced several scenarios corresponding to possible and different "socio economical" trajectories. (CARTER & HULME 2000) used four of the many established scenarios which are referred to as B1, B2, A1 and A2. The changes in the emissions of the greenhouse gases by 2100 relative to the emission as of 2000 were taken as a decrease of 4 % (B1 scenario of low emission) to a maximum increase of 320 % (A2 scenario of high emission, close to what became known as "business as usual", i.e., the emissions will continue to increase as in the last decades). The concentration of atmospheric CO_2 will increase from 370 ppmv in 1999 to about 550 ppmv by 2100 (B1 scenario) or even more to 830 ppmv (A2 scenario) or three times the concentration levels prior to the industrial era. The concentrations of the other greenhouse gases (mainly CH_4, N_2O and the tropospheric O_3) also increase in these scenarios. The remaining two scenarios (B2 and A1) are similar to each other and lie between the scenario of low emission (B1) and the one of high emission (A2).

Figures 8 and 9 (extracted from CARTER & HULME 2000), show scatter plots for possible seasonal variations of temperature and precipitation for the northern part of South America (NSA), including Amazonia (10°N-20°S and 35°W-80°W) for 2020, 2050 and 2080. In general, an increase of about 1 °C (in B1 scenario) to more than 6 °C (in scenario A2) by 2080 is predicted. With respect to precipitation, the uncertainty level is high. The results from several numerical simulation experiments do not show reasonable agreement among themselves. For example, some studies for the MAM, JJA and SON trimesters (Fig. 3) indicate an increase in precipitation while others indicate a decrease. The numerical results are somewhat more concordant for the DJF trimester, all indicating an increase in precipitation. The changes in precipitation lie between 0 and $\Rightarrow$ 3 % for the B1 scenario and between 0 and $\Rightarrow$ 10 % (up to 15 % for MAM) for the A2 scenario by 2080. The uncertainty level with respect to changes in frequency of the climatic extremes is still higher than that of the precipitation distribution. Since an increase in the air temperature near the surface will increase the ability of the air to retain more water vapor, one may expect that there will be an "acceleration" in the hydrological cycle, increasing the number of extreme events such as severe thunderstorms. Although this seems to be a plausible hypothesis, it certainly needs observational evidence.

The uncertainty with respect to the direction of the changes in the precipitation makes it impossible at present to assess the impacts of the global climate changes on

the Amazon ecosystems. If there is a reduction in the precipitation, then this decrease adds to the predicted reductions resulting from deforestation thus increasing the chances of fires and the reduction of species less tolerant to dry conditions. On the other hand, if there is an increase in precipitation, this would have an opposite effect counteracting the reduction brought about by deforestation, thus contributing to more favorable conditions for the maintenance of the ecosystems and the species.

With respect to the temperature changes it is noticed that an increase in the global temperature follows an increase of the surface temperature caused by deforestation (NOBRE et al. 1991). The various numerical experiments dealing with the replacement of native forests by pasture and crop fields in the Amazon Basin, supported by the observations made during ABRACOS (GASH & NOBRE 1997) and the LBA (Large scale Biosphere-Atmosphere experiment) do indicate an increase of 1-2 °C due to this land use practice. This increase is larger (lower) than the predicted one using the scenario B1 (A2) by the end of the century. Most probably, the effects of a temperature increase would enhance the chances of forest fires due to dryness of the vegetation and its flammability accelarated by raising temperatures (NEPSTEAD et al. 1999).

The predicted temperature increases would have a positive feedback and would, in return, raise the susceptibility of the ecosystems to global climate changes due to the greenhouse effect and to regional changes caused by deforestation. However, the uncertainty concerning how the changes in the precipitation regimen will take place, prevents knowing whether the climatic feedback would be positive or negative. It is hoped that this uncertainty will be lessened within the next decade when more realistic numerical models become available.

Discussion

Attempting to answer the fundamental questions "of how the deforestation of Amazonia will affect the global and regional climate changes and how, in return these will affect the ecosystems" we have concluded that the relation between RCCs and GCCsis directly associated with anthropogenic activities and therefore sensitive to social, economical and political interventions. The RCCs are caused by actions within the realm of the Brazilian sociopolitical scenario, and prone to changes through the implementation of public policies regulating the sustained use of the renewable resources. On the other hand, the GCCs belong to an international arena, and are caused by the high emission rates of greenhouse gases by the developed countries. The effects of the RCCs could be abated if the developed countries would endeavor to reduce the present emission levels as documented in IPCC meetings and collaborate in the implementation of a regulation to curb the carbon emissions, in accordance to the Kyoto Protocol.

The relation between the RCCs and the GCCs surpass scientific investigation of the atmosphere-biosphere system, and, leads to strong social, political and economical implications concerning the rational occupation of Amazonia. Regarding the RCCs, it is necessary to expand the scientific knowledge of the effects of these changes in the atmospheric composition on the ecosystems of the planet, and to strengthen regulations conducive to the substitution of the present economical model, responsible for the high emission rates of greenhouse effects. This enhancement is linked to political and economical aspects concerning the implementation of controlling mechanisms to curb

the emissions of CO_2 and other greenhouse gases in accordance with the guidelines of the IPCC.

In summary:
Regarding the RCCs:

- The cycle "replacement of native forests by farms or pasture ⇒ development of nonproductive and unsustainable agricultural and cattle raising activities ⇒ abandonment of degraded areas ⇒ new deforestation events" is harmful because it promotes further deforestation and the exhaustion of the natural resources. The transformation from native forests to pastures/crop fields implies a transfer of carbon (in the form of carbon dioxide) from the biosphere into the atmosphere aggravating the "global anthropogenic climate effect".
- The CO_2 emission by the forests should be avoided through the control of the traditional forms of land occupation. The key to reverse the processes of regional deforestation is to identify the human needs and demands and to have a governmental strategy to promote a sustainable regional development.

Regarding the GCCs:

- The increase in atmospheric CO_2 contributes to the global warming thus emphasizing the importance of the scientific component of the problem. The existing uncertainties in the climate models, mainly with respect to the precipitation, do not allow conclusive answer to the fundamental question of whether the feedback of this meteorological parameter is positive or negative. In the case of a decrease in the precipitation, the effects on the regional and global increases in temperature are in the same direction, thus accelarating the chances of forests fires.

What to do?
Regarding the sustainable use of the natural resources:

- Sustainable Forest Exploration (SFE): Implement policies and projects to assess the economical component of the SFE, introducing the conservation of biodiversity as an aggregated value to determine whether the SFE activity is appropriate or should be banned.
- Sustainable Agrosilviculture Systems (SAS): Implement, on a commercial scale, projects which would allow identification of the bottlenecks and search for adequate solutions to be amply disseminated in the degraded areas.
- Access to Genetic Resources (AGR): Develop procedures and regulations aiming at the implementation of bio-prospect projects endorsed by the Biological Diversity Convention, with fair and efficient sharing of the benefits among the local natives.

Regarding the Development of Models:

- Regional Models: The integrated use of biospheric and atmospheric data in the regional models will allow an improvement of the physical parametrizations so they can be used as powerful tools to study the RCCs and their effects on the GCCs. Their results will be of importance for the decision makers.
- Global Climatic Models: They will be used to examine the role of the greenhouse gases on the energy budget of the planet and their effects on the dynamics of global climate. They are instrumental in providing useful information regarding the influence

of the global warming on the Amazonian ecosystems.

- Development of specific models to predict the annual fixation rate of CO_2 by the native forests.
- Socio-economical models: Study the dynamics of the triangle society – economics - politics in the context of anthropogenic forcing, change in land use and their effects on the RCCs and GCCs.

Regarding Public Policies:

- Provide the decision makers with the available scientific tools in order to design projects for a sustainable use of the natural resources, in order to attain tangible and desirable economical, social and environmental results.
- Implement sustainable agrosilviculture systems in the degraded areas, in order to allow the continuation and the survival of human occupation, lessening the threat of new deforestation of native forests.
- Implement sustainable development projects which can be used as a model for the management of degraded areas, ensuring the permanency of the populations and avoiding the emigration to urban centers, consequently minimizing the social problems present in most of the large cities.
- Implement projects in degraded areas to mitigate the CO_2 concentration through integrated agrosilviculture systems of multiple use, to recreate natural ecosystems with the purpose of climate control and biodiversity conservation.
- Establish a minimum wage to local workers and scholarship programs in order to significantly increase the educational level of the children and adolescents who live in rural areas in Amazonia. The primary and secondary schools should include courses on environmental awareness, technical level courses adapted to the local needs and the pursuit of economically attractive alternatives to be used in lieu of non sustainable practices.

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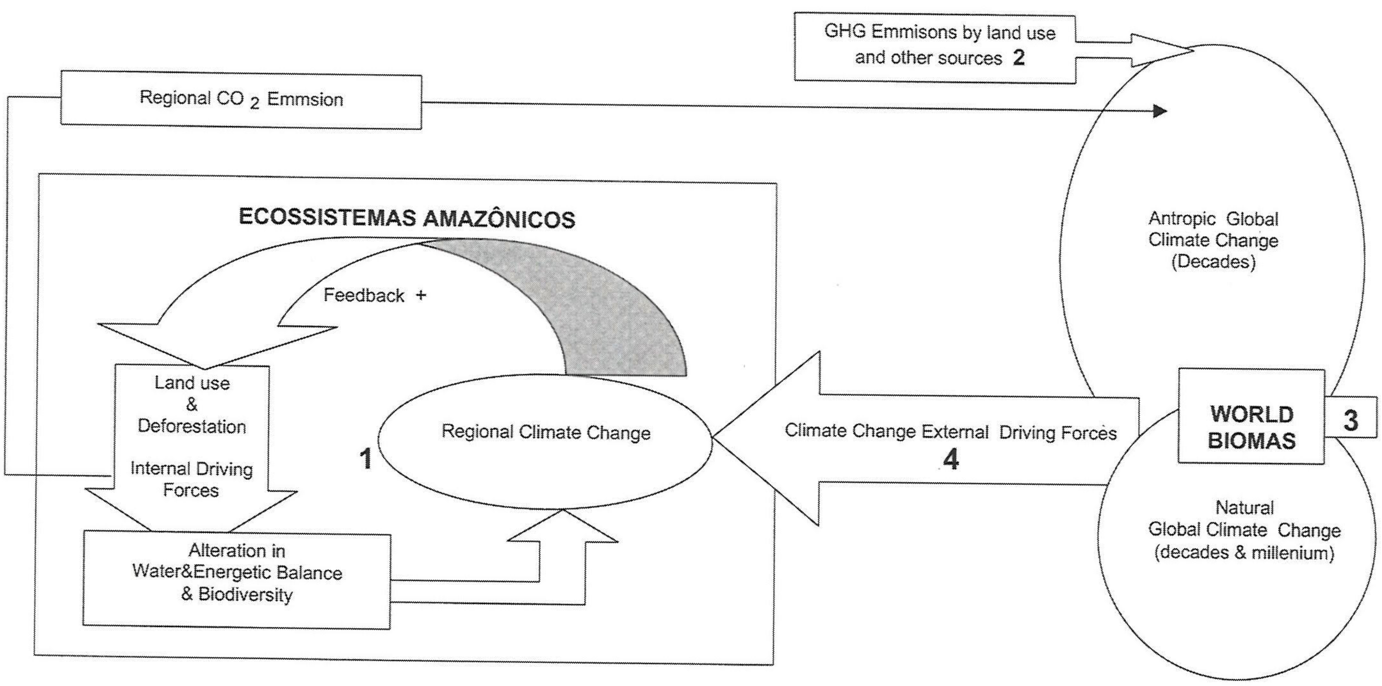
Table 1: Average temperatures (°C) for some Amazonian cities.

Cities	Latitude	Longitude	J	F	M	A	M	J	J	A	S	O	N	D	Year
			Mouth												
Taperinha - PA	2°24'S	54°41'W	25,2	25,3	25,2	25,4	25,5	24,8	24,4	25,6	25,8	25,7	25,3	25,4	25,5
Belém - PA	1°27'S	48°29'W	25,6	25,5	25,4	25,7	26,0	26,0	25,9	26,0	26,0	26,2	25,5	26,3	25,9
Marabá - PA	5°21'S	49°07'W	25,9	26,6	25,8	26,3	26,9	26,4	26,8	26,6	26,9	27,1	26,9	26,1	26,4
Óbidos - PA	1°55'S	55°31'W	26,2	25,9	25,8	25,8	25,8	25,9	26,0	26,9	27,0	28,0	27,8	27,2	26,5
Santatém - PA	2°26'S	54°42'W	25,8	25,5	25,5	25,6	25,6	25,4	25,4	26,2	26,7	27,0	26,9	26,5	26,0
Caraiari - AM	4°52'S	66°54'W	26,3	26,1	26,4	26,2	25,8	25,6	25,3	26,2	26,6	26,6	26,6	26,6	26,2
Humaitá - AM	7°31'S	63°02'W	25,2	25,3	25,4	25,4	25,5	25,2	25,2	26,4	26,3	26,3	26,0	25,7	25,7
Itacoatiara - AM	3°08'S	58°25'W	26,7	26,4	26,4	26,5	26,7	26,7	26,8	27,8	28,1	28,2	28,1	27,6	27,1
Manaus - AM	3°08'S	60°01'W	25,9	25,8	25,8	25,8	26,4	26,6	26,9	27,5	27,9	27,7	27,3	26,7	26,7
Manicoré - AM	5°49'S	61°19'W	26,2	25,8	26,1	26,2	26,3	26,3	26,1	27,0	27,0	27,2	27,2	26,9	26,5
Cruzeiro do Sul - AC	7°38'S	72°36'W	24,4	24,6	24,4	24,2	24,1	23,4	22,9	23,8	24,5	24,6	24,7	24,6	24,2
Macapá - AP	0°02'N	51°03'W	26,8	26,4	26,1	26,3	26,8	26,7	25,5	29,3	28,3	28,3	28,0	27,3	27,3
Porto Velho - RO	8°46'S	63°54'W	25,1	25,2	25,3	25,3	25,3	25,1	25,0	26,4	26,6	26,1	25,8	25,4	25,6
Boa Vista - RR	2°49'N	60°40'W	27,7	28,0	28,3	28,2	27,0	26,2	26,1	26,6	28,1	28,8	28,6	28,3	27,6
Carolina - MA	7°20'S	47°28'W	25,6	25,6	25,8	26,1	26,4	26,1	26,3	27,7	28,3	27,1	26,4	26,1	26,4
São Luiz - MA	2°31'S	46°'W	26,8	26,4	26,3	26,3	26,3	26,4	26,2	26,6	27,0	27,2	27,3	27,2	26,7

Fig. 1:
Regional and global climate change in Amazonia.
(1) Human action, trough the alterations in land use and deforestation, alter the water balance, solar radiation and increase release of carbon into atmosfera and also cause biodiversity loss. Those, when present in large areas may cause regional climate changes - RCC, mainly by the increase in temperature and reduction of plant transpiration and preciptation which affect the ecosystems. Through feedback, RCC increases forest fragmentation and fires. These factors cause regional environmental depletion and increase the extinction rates of different species. Deforestation and fires release CO_2 to the atmosphere, being that the Amazonian region is responsible for 3-5 % of the world rate of carbon emission. **(2, 3)** Other greenhouse gases (GHG) are released into the atmosphere by external antropic forces causing global climate changes which affect all ecosystems in the planet. **(4)** In return, the global climate changes add to the regional changes, causing a higher impact over the Amazonian ecosystem.



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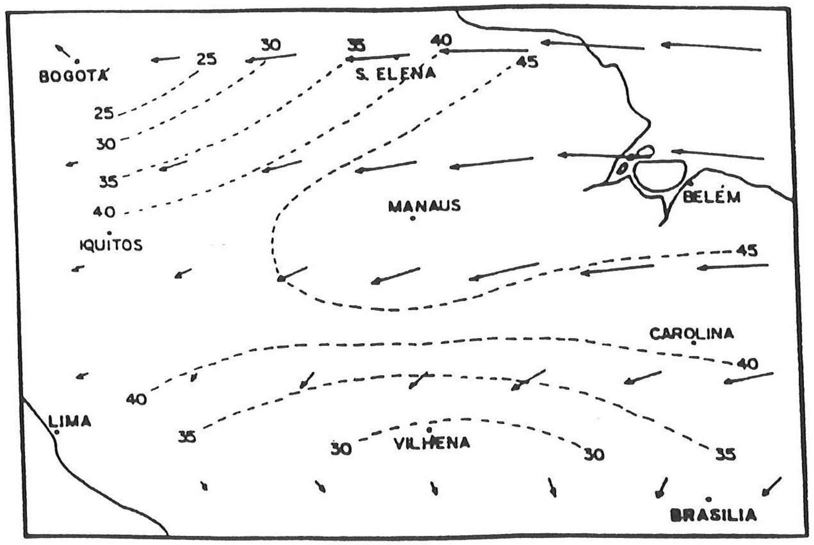

Fig. 2:

Values of vectorial field $\vec{Q} = \vec{Q}_{\lambda} + \vec{Q}_{\lambda}$. Mean of period 1972-1975, obtained for the 5° latitude x 5° longitude squares (1cm = 2000 g/cm.s). Broken line: precipitable water in mm.

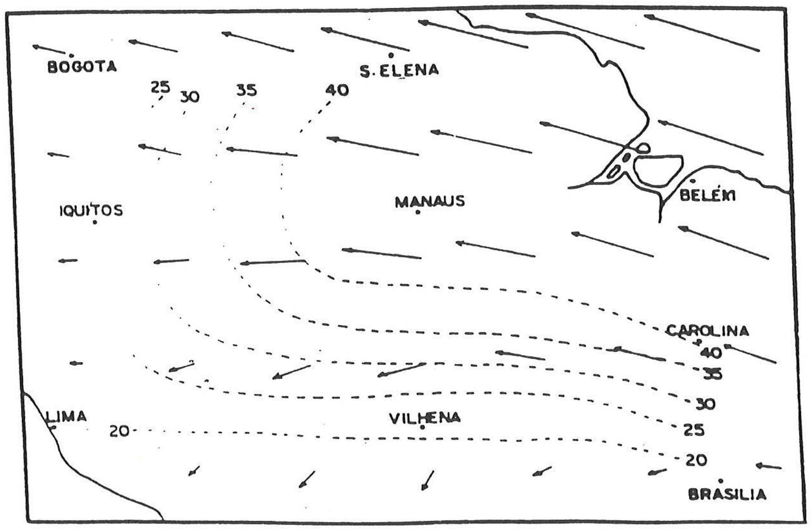

Fig. 3:

Values of vectorial field $\vec{Q} = \vec{Q}_{\lambda} + \vec{Q}_{\lambda}$. Mean of period 1972-1975, September, obtained for the 5° latitude x 5° longitude squares (1cm = 2000 g/cm.s). Broken line: precipitable water in mm.

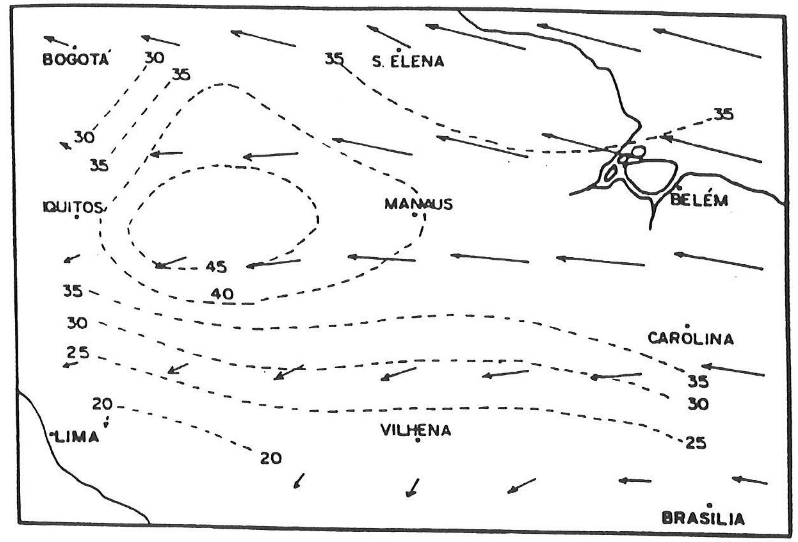

Fig. 4:

Values of vectorial field $\vec{Q} = \vec{Q}_{\lambda} + \vec{Q}_{\lambda}$. Mean of period 1972-1975, June, obtained for the 5° latitude x 5° longitude squares (1cm = 2000 g/cm.s). Broken line: precipitable water in mm.

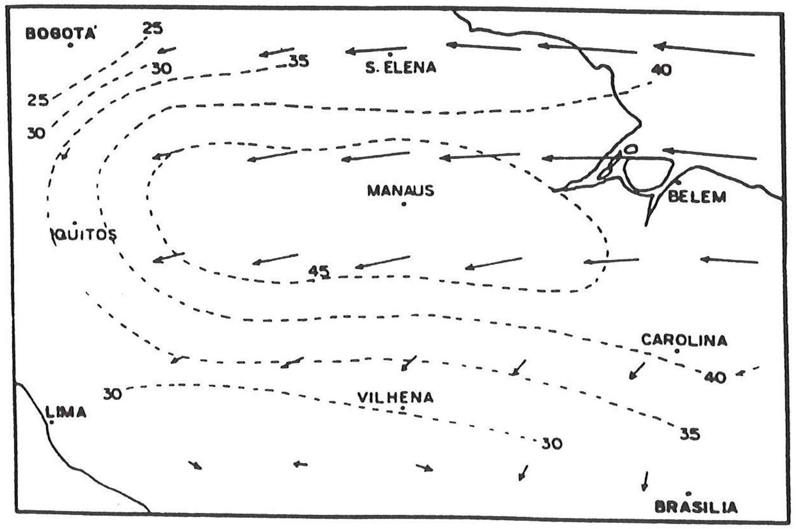

Fig. 5:

Values of vectorial field $\vec{Q} = \vec{Q}_{\lambda} + \vec{Q}_{\lambda}$. Mean of period 1972-1975, December, obtained for the 5° latitude x 5° longitude squares (1cm = 2000 g/cm.s). Broken line: precipitable water in mm.

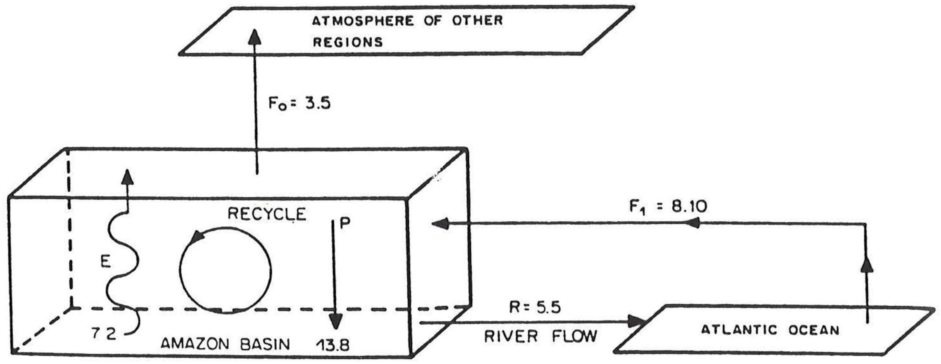

Fig. 6:
Water cycle in Amazonia depends, in part, on the water vapor circulation due to the presence of the forest which is, at the same time, related to P = precipitation, E = plant transpiration, R = river flow, Fi = water vapor flow from the Atlantic, Fq = flow out of the Amazon basin (all numbers are multiplied by 10^{12} m^3).

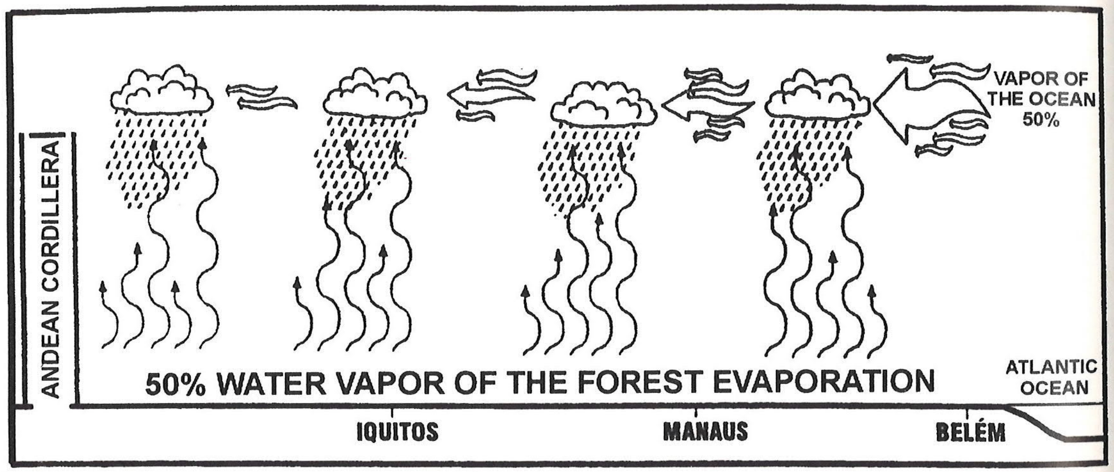

Fig. 7:
Water cycling in Amazonia. Approximately 50 % of the water vapor which produces rains comes from the Atlantic Ocean. The other 50 % is produced by the evapotranspiration mechanism inside the forests.

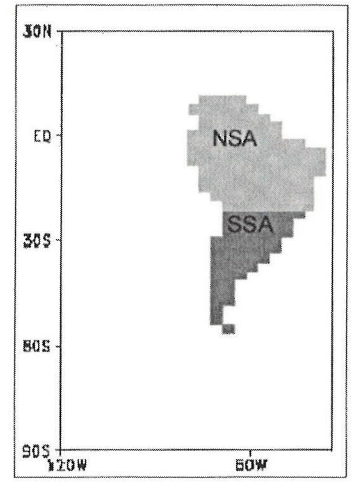

Fig. 8A:
Map depicting the two regions of South America. Figure 2 refers to the northern part of South America (NSA). The regions are defined in the grid of the climate model HadCMS. The regional domains are slightly different from one climate model to the other (adapted from CARTER & HULME 2000).

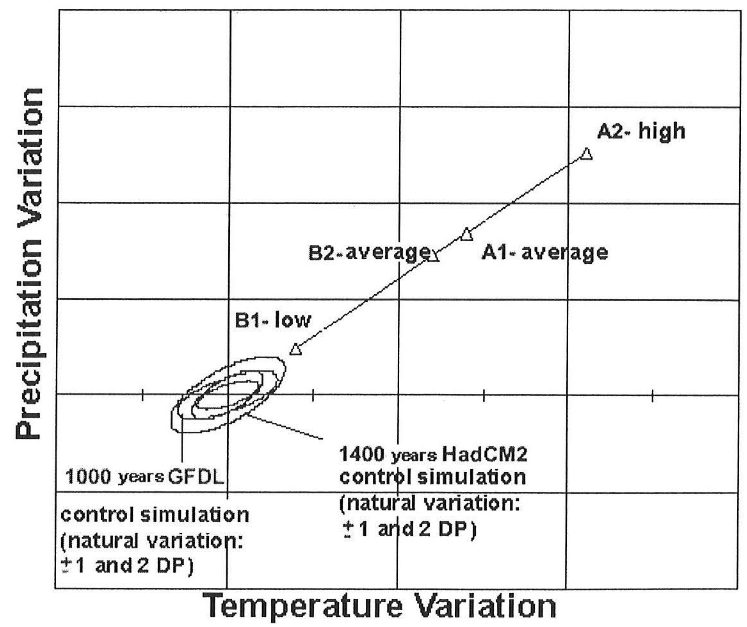

Fig 8B:
Main characteristics of the scatter plots of the seasonal temperature and precipitation changes for the four SRES emission scenarios (adapted from CARTER & HULME 2000).

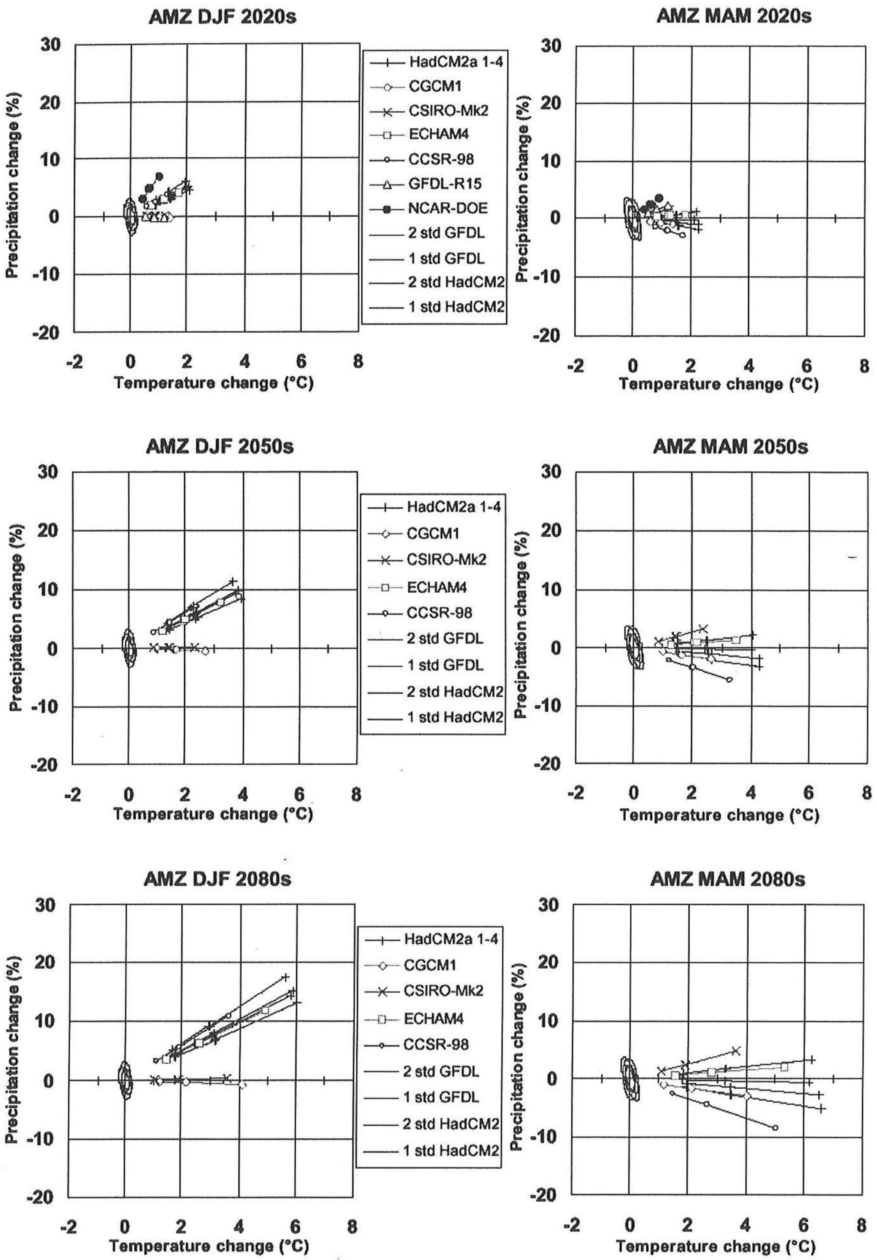

Fig. 9A:
Northern South America (NSA): December-February and March-May (adapted from CATER & HULME 2000).

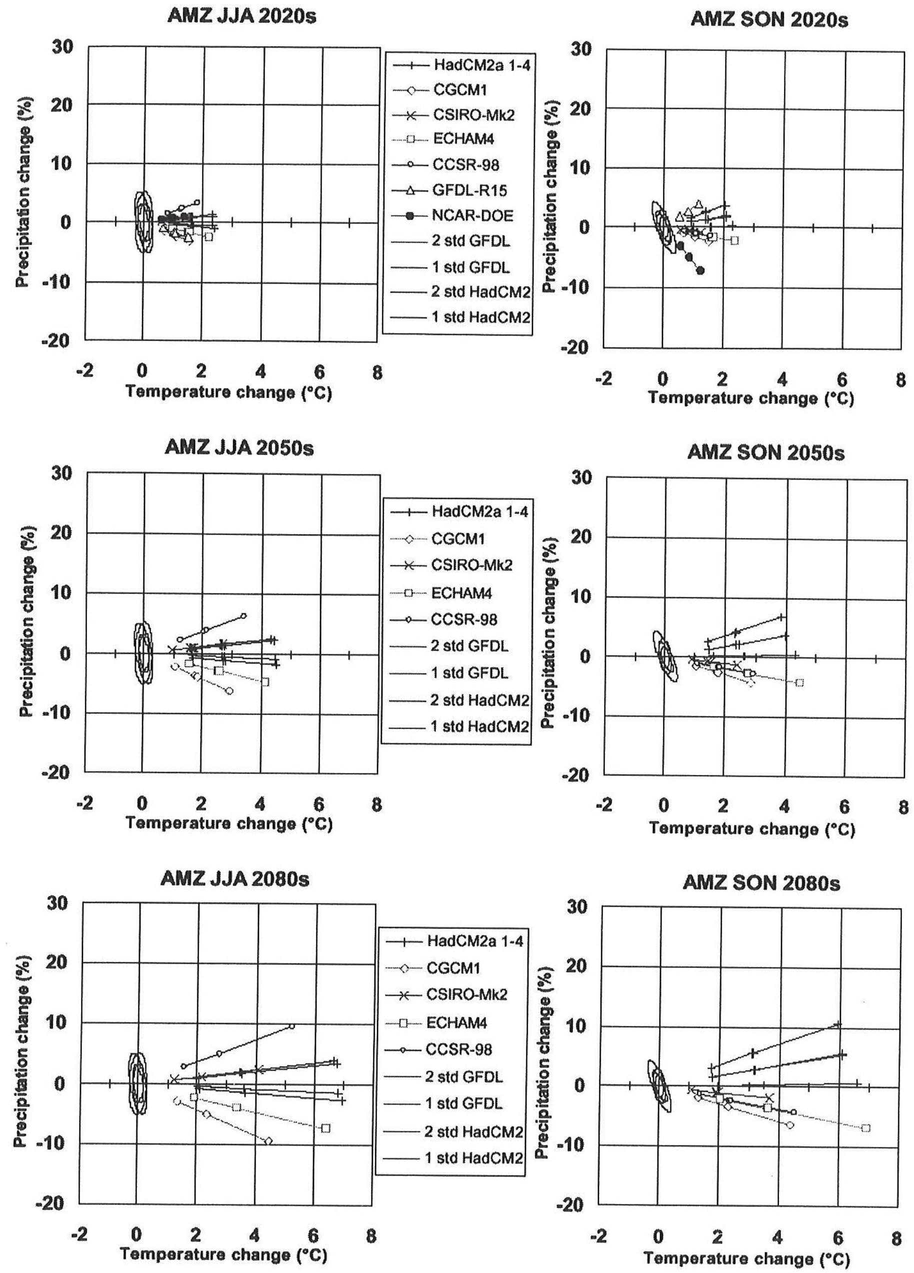

Fig. 9B:
Northern South America (NSA): June-August and September-November (adapted from CARTER & HULME 2000).